Secure and Robust Image Watermarking Scheme Using Homomorphic Transform, SVD and Arnold Transform in RDWT Domain

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Abstract. The main objective for a watermarking technique is to attain imperceptibility, robustness and security against various malicious attacks applied by illicit users. To fulfil these basic requirements for a scheme is a big issue of concern. So, in this paper, a new image watermarking method is proposed which utilizes properties of homomorphic transform, Redundant Discrete Wavelet Transform (RDWT), Arnold Transform (AT) along with Singular Value Decomposition (SVD) to attain these required properties. RDWT is performed on host image to achieve LL subband. This LL subband image is further decomposed into illumination and reflectance components by homomorphic transform. In order to strengthen security of proposed scheme, AT is used to scramble watermark. This scrambled watermark is embedded with Singular Values (SVs) of reflectance component which are obtained by applying SVD to it. Since reflectance component contains important features of image, therefore, embedding of watermark in this part provides excellent imperceptibility. Proposed scheme is comprehensively examined against different attacks like scaling, shearing etc. for its robustness. Comparative study with other prevailing algorithms clearly reveals superiority of proposed scheme in terms of robustness and imperceptibility.

Keywords
Arnold transform, homomorphic transform, RDWT, SVD, watermarking.

1. Introduction

In recent times, forgery related to various digital multimedia such as images, video etc. is easily carried out by illegitimate attackers. So, in order to provide secure transmission of information among users, there must be a technique developed which easily resolves these challenges. Image watermarking is one of the methods which provides possible solution to this problem. In image watermarking, secret information which is generally in form of image is concealed inside host image such that it becomes imperceptible to users.

The key features for a watermarking algorithm are robustness, imperceptibility, security and capacity. Robustness measures efficacy of algorithm towards various unintentional attacks, whereas imperceptibility signifies both images should be visually similar. Capacity defines data payload. Lastly, security secures algorithm against unauthorized users. Depending on working domain, watermarking schemes are classified into two parts (i) spatial domain and (ii) transform domain. Since transform domain provides good robustness in comparison with spatial domain, hence, they are preferred. Depending on information needed at receiver side, the watermarking techniques are categorised as non-blind, semi-blind and blind. In non-blind method, both original image and watermark are essential, whereas in semi-blind, partial information of watermark is needed. In blind schemes, there is no requirement of original and watermark images. To improve these properties, simultaneously fusion of various transforms such as Discrete Cosine Transform (DCT) and DWT along with SVD is used.

Authors in [9] reported a method in which directly watermark is embedded into SVs of cover image. Researchers suggested a method [10] in which cover image is decomposed in various frequency subbands using RDWT, afterwards SVD is performed on all subbands. SVs of watermark are embedded into SVs of subbands. However, this method results in non-
2. Background

A brief overview of homomorphic transform, RDWT, SVD and AT are presented in this section.

2.1. Homomorphic Transform

Image a \((m_1, m_2)\) is considered as product of two components i.e. illumination \(i (m_1, m_2)\) and reflectance \(r (m_1, m_2)\) [18], where \((m_1, m_2)\) denotes spatial coordinates.

\[
a(m_1, m_2) = i(m_1, m_2) \cdot r(m_1, m_2).
\]

Both components present in Eq. (1) are made separable using natural logarithm.

\[
\ln(a(m_1, m_2)) = \ln(i(m_1, m_2)) + \ln(r(m_1, m_2)).
\]

Fast Fourier Transform (FFT) is performed on both sides in Eq. (2).

\[
A(u, v) = A_i(u, v) + A_r(u, v).
\]

Afterwards, frequency domain output \(A(u, v)\) is passed through High Pass Filter (HPF) \(H(u, v)\).

\[
F(u, v) = A_i(u, v) \cdot H(u, v) + A_r(u, v) \cdot H(u, v),
\]

where \(F(u, v)\) denotes output obtained from HPF. Inverse FFT is performed on Eq. (3).

\[
f(m_1, m_2) = \mathcal{F}^{-1}(F(u, v)),
\]

where \(f(m_1, m_2)\) is output in logarithmic domain. Filtered output image \(g(m_1, m_2)\) is computed as:

\[
g(m_1, m_2) = \exp(f(m_1, m_2)).
\]

Figure 1 depicts schematic diagram for homomorphic transform.

2.2. Redundant Discrete Wavelet Transform

Though DWT provides excellent multiresolution analysis of signal by decomposing the image into four frequency subbands, i.e. LL, HL, LH and HH, major concern in implementation of DWT is shift variance. DWT employs down samplers in filtering process due to which shift variance arises. In order to remove this problem, down-sampling process is completely eliminated and shift invariance is attained. This process results in RDWT [19]. The size of each subband remains same after applying RDWT. Therefore, RDWT provides better imperceptibility by embedding watermark in desired frequency subband. Robustness of scheme is also enhanced due to its shift invariance property. Figure 2 shows RDWT decomposition of "Cameraman" image.
2.3. Singular Value Decomposition

SVD decomposes a given image ‘B’ of size $M \times N$ into three matrices ‘U’, ‘V’ and ‘S’, where U and V are orthogonal matrices [20], [21] and [22]. ‘S’ is a diagonal matrix which consists of SVs which are arranged in decreasing order.

$$B = USV^T.$$  

SVD is a popular analysis performed on image because it provides excellent stability as SVs do not change on slight modifications performed on image such as translation, shearing etc. which enhances robustness of algorithm.

2.4. Arnold Transform

In order to enhance security of images while transmission over channel, generally they are scrambled using various techniques. Arnold transform is one method employed for scrambling of image. Mathematically it is given as:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 2 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \mod N,$$

where $\begin{pmatrix} x' \\ y' \end{pmatrix}$ and $\begin{pmatrix} x \\ y \end{pmatrix}$ denotes pixel values of image after and before scrambling. ‘N’ defines size of image. This mapping is periodic with period ‘T’. So, after fixed number of iterations, original image is recovered back [23], [24] and [25]. Figure 3(a) shows original image whereas Fig. 3(b) represents one-time AT of ‘Lena’ image.

3. Proposed Algorithm

Proposed watermark embedding and extraction algorithms are elaborated in this section. Fusion of homomorphic transform, RDWT, SVD along with AT are used in proposed algorithm. Reflectance component of LL subband of cover image is selected for embedding of watermark. Since reflectance component contains major image information, so a high degree of imperceptibility is achieved by embedding watermark into this component, whereas use of RDWT and SVD strengthens robustness of algorithm. Arnold transform enhances security of proposed algorithm. 2-D Gaussian Low Pass Filter (LPF) and HPF are employed in homomorphic transform.

$$H_{LPF}(u,v) = e^{-\frac{((u-\mu_u)^2 + (v-\mu_v)^2)}{2R^2}},$$

where ‘$H_{LPF}$’ denotes transfer function of LPF as presented in Eq. (9) and corresponding transfer function for HPF ‘$H_{HPF}$’ is given below:

$$H_{HPF}(u,v) = 1 - H_{LPF}(u,v).$$

Illumination ‘I’ and reflectance ‘R’ components are separated with help of these filters. This work mainly focuses to develop an imperceptible, robust and secure watermarking technique. Figure 4 and Fig. 5 show embedding and extraction algorithms block diagram.
3.1. Embedding Algorithm

- First level RDWT is performed on host image ‘A’ which decomposes it into four subbands, i.e. LL, HL, LH and HH.
- Homomorphic transform is performed to LL subband to separate out illumination ‘I’ and reflectance ‘R’ components.
- Further SVD is performed on reflectance matrix for obtaining SVs.
  \[
  \text{SVD}(\text{LL}_R) = USV^T. \quad (11)
  \]
- Now, AT is performed on watermark ‘W’.
- Scrambled watermark ‘W’ is embedded into SVs of ‘\text{LL}_R’.
  \[
  A^{\text{new}} = S + \alpha \ast W, \quad (12)
  \]
  where $\alpha = 0.005$.
- SVD is applied on ‘$A^{\text{new}}$’.
  \[
  A^{\text{new}} = U_W S_W V_W^T. \quad (13)
  \]
- New modified reflectance matrix ‘$R^{\text{mod}}$’ is computed as:
  \[
  R^{\text{mod}} = U_W V^T. \quad (14)
  \]
- Inverse homomorphic transform is performed on ‘$R^{\text{mod}}$’ according to Eq. (15) and Eq. (16):
  \[
  Z^{\text{new}} = R^{\text{mod}} + I, \quad (15)
  \]
  \[
  C = \exp(Z^{\text{new}}) - 1. \quad (16)
  \]
- Watermarked image ‘$A_w$’ is obtained by taking inverse RDWT of ‘$C$’ with other unaltered wavelet coefficients.

3.2. Extraction Algorithm

- One level RDWT is performed on watermarked image ‘$A_w$’ to obtain four subbands LL, HL, LH and HH.
- Homomorphic transform is applied to LL subband using similar LPF and HPF as used in embedding.
method to separate out illumination ‘I_w’ and reflectance ‘R_w’ components.

- Now SVs of ‘R_w’ are obtained using SVD.

\[
SVD(LL_{R_w}) = U^*S^*V^*T.
\]  

- Matrix ‘F*’ which contains watermark is evaluated as:

\[
F^* = U_WS^*V_W^T.
\]  

- Scrambled watermark ‘W*’ is extracted according to Eq. (19).

\[
W^* = \frac{(F^* - S)}{\alpha}.
\]  

- Original watermark is recovered by applying inverse AT to ‘W*’.

4. Simulation Results

To evaluate performance of proposed scheme, it is tested on various standard images which are chosen as ‘Lena’, ‘Bridge’, ‘House’, ‘Boat’, and ‘Man’ of size 512 × 512 as depicted in Fig. 6(a) Fig. 6(b) Fig. 6(c) Fig. 6(d) and Fig. 6(e) ‘MNNIT’ logo is taken as watermark of size 512 × 512 as presented in Fig. 6(f) whereas Fig. 7(a), Fig. 7(b), Fig. 7(c), Fig. 7(d) and Fig. 7(e) represents the watermarked images and extracted watermark is presented in Fig. 7(f) MATLAB R2015a is used for implementation of proposed algorithm.

![Fig. 6: Original images (a) Lena, (b) Bridge, (c) House, (d) Boat, (e) Man and (f) Watermark ‘MNNIT’ logo.](image)

![Fig. 7: Various watermarked images (a) Lena, (b) Bridge, (c) House, (d) Boat, (e) Man and (f) Extracted watermark ‘MNNIT’ logo.](image)

Various performance parameters are evaluated to measure imperceptibility and robustness of proposed technique. Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index (SSIM) metrics are used to evaluate imperceptibility of proposed technique. Mathematically PSNR is given as:

\[
PSNR = 10 \log_{10} \left( \frac{255^2}{MSE} \right),
\]  

where \( MSE \) is mean square error computed between original ‘X’ image and watermarked ‘Y’ image.

\[
MSE = \frac{1}{N^2} \sum_{a=0}^{N-1} \sum_{b=0}^{N-1} [X(a,b) - Y(a,b)]^2.
\]  

Another parameter used is \( SSIM \) which evaluates structural similarity between original and watermarked images. Eq. (24) presents its mathematical description.

\[
SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1) \cdot (2\sigma_{xy} + c_2)}{\mu_x^2 + \mu_y^2 + c_1 \cdot (\sigma_x^2 + \sigma_y^2 + c_2)},
\]  

where \( \mu_x, \mu_y \) are mean of \( x \) and \( y \), \( \sigma_x, \sigma_y \) are standard deviations of \( x \) and \( y \), whereas \( \sigma_{xy} \) is covariance between \( x \) and \( y \), respectively.

Robustness of proposed algorithm is measured under various attacks using Normalized Coefficient Correlation (NCC), mathematically defined in Eq. (25) which computes similarity between original and extracted watermark images.

\[
NCC = \frac{\sum_{i=1}^{p} \sum_{j=1}^{q} [W(i,j) \cdot W^*(i,j)]}{\sqrt{\sum_{i=1}^{p} \sum_{j=1}^{q} [W(i,j)]^2 \cdot \sum_{i=1}^{p} \sum_{j=1}^{q} [W^*(i,j)]^2}},
\]  

where \( W(i,j) \) is watermark image and \( W^*(i,j) \) is extracted watermark.

Figure 8(a) and Fig. 8(b) show histograms for original and watermarked ‘Lena’ images from which it can be easily inferred that proposed scheme offers good imperceptibility. Table 1 tabulates values of various performance parameters under no attacks for different watermarked images.

<table>
<thead>
<tr>
<th>Image</th>
<th>PSNR (dB)</th>
<th>NCC</th>
<th>SSIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lena</td>
<td>68.5287</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Bridge</td>
<td>72.1434</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>House</td>
<td>65.1710</td>
<td>1.00</td>
<td>0.9999</td>
</tr>
<tr>
<td>Boat</td>
<td>65.9651</td>
<td>1.00</td>
<td>0.9999</td>
</tr>
<tr>
<td>Man</td>
<td>66.0615</td>
<td>1.00</td>
<td>0.9999</td>
</tr>
</tbody>
</table>

Figure 9 given below demonstrates watermarked ‘Lena’ image subjected to various attacks such as salt & pepper noise (0.001), Gaussian filtering (3 × 3), histogram equalization and rotation (20°) whereas Fig. 10 shows corresponding extracted watermark images.
Robustness analysis is presented in Tab. 2 where $NCC$ values for extracted watermark are computed under varieties of attacks applied on different watermarked images. By observing Tab. 2 it can be easily inferred that proposed approach exhibits good robustness as $NCC$ values are lying in proximity of $+1$ which signifies its efficacy. Highest $NCC$ of 1.00 is attained for several watermarked images under numerous attacks.

Figure 11 represents $PSNR$ values for various watermarked images under varieties of attacks. Higher values of $PSNR$ are attained by proposed algorithm which clearly signifies its high imperceptibility. Highest $PSNR$ of 53.6790 dB for Gaussian filtering attack is attained whereas $PSNR$ of 7.1367 dB for rotation ($20^\circ$) attack is obtained. It is clearly illustrated in Fig. 11 that proposed approach attains $PSNR$ well above 25 dB for most of the attacks.

Table 3 clearly states superiority of our scheme by comparing it with other prevailing schemes such as [9], [11], [12] and [12]$^a$ where [12]$^a$ denotes block-based technique used in [12] present in the literature. From comparative analysis depicted in Tab. 3 it is quite obvious that developed method delivers better $NCC$ values which clearly signifies high robustness of the proposed technique. Higher values of $NCC$ are reported for same attacks as applied to existing methods which signifies efficacy of our method. ‘-’ stands for not reported in Tab. 3.
5. Conclusion

In this paper, a novel image watermarking technique is developed which uses homomorphic transform, RDWT, SVD and AT. Embedding of watermark in reflectance component obtained by homomorphic transform of RDWT transformed host image results in excellent imperceptibility, whereas RDWT and SVD improve robustness of the scheme. The proposed scheme is fast and reliable as it does not require original host image for extraction and reliability is enhanced by scrambling of watermark. LL subband demonstrates good robustness towards various attacks like histogram equalization, scaling, rotation etc. The proposed algorithm is highly imperceptible and robust as indicated by higher values of performances metrics. Further superiority of proposed scheme is exhibited by comparing it with other existing schemes such as [9], [11], [12] and [12]a. This work can be extended for improving imperceptibility and robustness such that trade-off between them is maintained and further investigations will be performed for developing a watermarking technique free from FPP.

References


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